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HYPERSONIC AERODYNAMIC CHARACTERISTICS OF A VARIABLE-DIHEDRAL DELTA-WING SPACECRAFT CONFIGURATION

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16. Abstract

An investigation of a variable-dihedral delta-wing spacecraft concept has been conducted in the Langley hypersonic flow apparatus at a Mach number of 10.03. Angle of attack was varied from -5° to about 38° at angles of sideslip of 0° and -5°. Static longitudinal and lateral-directional characteristics were investigated for wing dihedral angles of 0°, 30°, 60°, 90°, and 110° for both 0° and 13° of wing toe-in.

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HYPERSONIC AERODYNAMIC CHARACTERISTICS OF A VARIABLE-DIHEDRAL DELTA-WING SPACECRAFT CONFIGURATION

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SUMMARY

Hypersonic wind-tunnel tests have been conducted to determine the static longitudinal and lateral-directional aerodynamic characteristics of a spacecraft configuration with a variable-dihedral delta wing over the angle-of-attack range from -5° to about 38°. Wing dihedral angles of 0°, 30°, 60°, 90°, and 110° at 0° and 13° of wing toe-in were investigated.

The model was longitudinally stable about the selected center-of-gravity position of 0.70 body length over the angle-of-attack range only for wing dihedral angles of 0° and 30° at both toe-in angles. Untrimmed maximum lift-drag ratios of about 2 and 1.9 were obtained for the wings with 0° dihedral at 0° and 13° toe-in, respectively. With 0° of wing toe-in, the model was directionally unstable for all dihedral angles except 110° at angles of attack below 14°. With 13° of wing toe-in, the model was directionally stable for the intermediate dihedral angles of 30°, 60°, and 90°. All combinations of wing dihedral and toe-in angles investigated resulted in positive effective dihedral over the test angle-of-attack range.

INTRODUCTION

The hypersonic aerodynamic characteristics of a spacecraft configuration, which may offer the capability of meeting a wide spectrum of cross-range requirements by use of variable-dihedral wings, are presented. The use of variable-dihedral lifting surfaces has been indicated to offer a wide range of trimmable angles of attack at hypersonic speeds. (See ref. 1.) In addition, these wings can contribute significantly to directional stability at hypersonic speeds by properly setting the toe-in angle and the dihedral angle. (See ref. 2.) Low subsonic characteristics for this concept are presented in reference 3.

The present tests were made in the Langley hypersonic flow apparatus at a Mach number of 10.03. The angle of attack was varied from about -5° to 38° at sideslip angles of 0° and -5°. The effects of wing dihedral angle and wing toe-in angle were investigated.

SYMBOLS

The static longitudinal aerodynamic characteristics are presented in the stability axis system and the lateral-directional aerodynamic characteristics are presented in the body axis system. All coefficients are normalized with respect to the projected planform area, length, and span of the body. The moment reference point corresponded to a center-of-gravity location at 70-percent body length, unless otherwise noted.

b reference span (maximum body span), 8.46 cm

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_{l_β} lateral-stability parameter, $\frac{\Delta C_l}{\Delta \beta}$; $\beta = 0^\circ$ and $\beta = -5^\circ$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_{n_β} directional-stability parameter, $\frac{\Delta C_n}{\Delta \beta}$; $\beta = 0^\circ$ and $\beta = -5^\circ$

C_Y side-force coefficient, $\frac{\text{Side force}}{qS}$

C_{Y_β} side-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$; $\beta = 0^\circ$ and $\beta = -5^\circ$

L/D lift-drag ratio

$(L/D)_{max}$ maximum lift-drag ratio

l length of body, 20.35 cm

M Mach number

q dynamic pressure, N/m^2 (lb/sq ft)

S projected planform of body alone, 85.68 cm^2

α angle of attack, deg

β angle of sideslip, deg

Γ wing dihedral angle, positive with tip up, deg

τ wing toe-in angle, positive with aft end of wing hinge line outboard, deg

Configuration designations:

B body

W wing

V vertical tail

DESCRIPTION OF MODEL

A sketch of the model used in the investigation is presented in figure 1 and photographs of the model are presented in figure 2. The model undersurface was semicircular at the nose and became a circular arc as the body flared rearward to form a highly swept delta planform. The upper-body cross section varied from semicircular at the nose to trapezoidal at the base and did not flare as did the lower surface. The juncture of the upper and lower body shapes therefore formed triangular horizontal planes aft of about the 50-percent body station upon which the 58° swept variable-dihedral wings were mounted. In theory, the flared underbody is shaped to provide hypersonic trim at high angles of attack (60° to 70°) with the wings at the maximum dihedral angle ($\Gamma = 110^{\circ}$) and acts as a heat shield during entry for the powered hinges of the wings. This volume is also a potential storage area for fuel or airbreathing engines which may be required for landing or subsonic cruise. The wings utilized NACA 2408 airfoil sections and the model was designed to allow tests at dihedral angles of 0°, 30°, 60°, 90°, and 110° at 0° and 13° of wing toe-in. In order to obtain 13° of toe-in, the wing dihedral hinge line was rotated from a position adjacent to the body to near the outer edge of the flared underbody; thereby the exposed wing area was increased and the wing leading-edge sweep was decreased. A center-line slab-wedge vertical tail, which corresponded to the small vertical tail used in reference 3, was tested on the model.

TESTS AND CORRECTIONS

The present investigation was made in the Langley hypersonic flow apparatus at a Mach number of 10.03. A brief description of this facility is given in reference 4. Tests were made at a stagnation temperature of approximately 621° C (1150° F) and a stagnation pressure of 6205 kN/m^2 (900 lb/sq in.) corresponding to a Reynolds number of 1.07×10^6, based on body length.

Forces and moments were measured with a sting-supported, six-component, water-cooled, strain-gage balance. The angle-of-attack range of the investigation was from approximately -5° to 38° at sideslip angles of 0° and -5°. Lateral-directional parameters C_{Y_β}, C_{n_β}, and C_{l_β} were calculated from increments obtained between angles of sideslip of 0° and -5° and therefore do not account for any nonlinearities which may exist in the intermediate sideslip range.

Angle of attack and angle of sideslip have been corrected for the effects of sting and balance deflection under load. The drag data represent gross drag in that the effect of base pressure is included in the measured drag values.

RESULTS AND DISCUSSION

Because of the preliminary nature of the configuration tested, there are no detailed analyses of the results; however, several areas of interest are briefly discussed.

Longitudinal Aerodynamic Characteristics

Model buildup characteristics.- Data for the body alone, body—vertical-tail, and complete configuration with $\Gamma = 0^\circ$ for $\tau = 0^\circ$ and 13° are presented in figure 3. The body-alone data indicate longitudinal instability, as anticipated, over the test angle-of-attack range. Higher angle-of-attack data are required to determine whether the configuration has a stable trim point. Untrimmed $(L/D)_{max}$ near $\alpha = 10^\circ$ was about 2.1.

Addition of the wing with $\Gamma = 0^\circ$ and $\tau = 0^\circ$ resulted in large increases in the lift variation, minimum drag, and longitudinal stability with increasing angle of attack. With $\tau = 13^\circ$ ($\Gamma = 0^\circ$) the minimum drag and lift variation with angle of attack were increased, over $\tau = 0^\circ$, and greater stability was obtained. This trend is not surprising since the method of obtaining $\tau = 13^\circ$ was to rotate each wing outboard about its apex; thereby the wing leading edge was unswept and the exposed wing area was increased. It is interesting to note that untrimmed $(L/D)_{max}$ was slightly reduced by the addition of the wings ($\Gamma = 0^\circ$) with $\tau = 0^\circ$ or $\tau = 13^\circ$ (2.0 and 1.9, respectively). Similar results were obtained in references 1 and 5 for lifting-body configurations with hypersonic L/D of about 1 and 2, respectively.

Effect of wing dihedral angle.- Data for the range of wing dihedral angles tested ($\Gamma = 0^\circ$ to $\Gamma = 110^\circ$) are presented in figures 4 and 5 for $\tau = 0^\circ$ and 13°, respectively. The data indicate a loss in lift, lift-drag ratio, and longitudinal stability with increasing wing dihedral angle. At $\tau = 0^\circ$ and $\tau = 13^\circ$, the complete configuration was longitudinally stable for $\Gamma = 0^\circ$ and $\Gamma = 30^\circ$ and unstable for dihedral angles above 30° within the experimental test range. The maximum trimmed angle of attack for these tests of 28° was obtained with $\Gamma = 30^\circ$ and $\tau = 0^\circ$. The pitching-moment curves indicate a range of trimmed angle of attack up to 28° and the data suggest that the configuration will trim at very high angles of attack with the wings positioned at a large dihedral angle.

Lateral-Directional Aerodynamic Characteristics

Model buildup characteristics.- The variation of C_{l_β}, C_{n_β}, and C_{Y_β} with angle of attack is presented in figure 6 to show the effect of model buildup on the lateral-directional stability characteristics.

The data for the configurations shown indicate all are directionally unstable with essentially no effect due to angle of attack. Addition of the vertical tail only slightly decreased the instability whereas a greater reduction was realized by addition of the wing with no dihedral ($\tau = 0^\circ$ or $\tau = 13^\circ$). The apparent ineffectiveness of the vertical tail is attributed to its size and location relative to the center of gravity. The favorable effect of the wing on lateral center of pressure has previously been noted on similar configurations at $M = 10$ in references 1 and 6. The body-alone and body-vertical tail had small values of the positive effective dihedral $\left(-C_{l_\beta}\right)$ and, as would be expected, the vertical tail was ineffective about $\alpha = 12^\circ$. Addition of the wings at 0° dihedral ($\tau = 0^\circ$ or 13°) increased the positive effective dihedral throughout the test angle-of-attack range.

Effect of wing dihedral and toe-in angles.- The effects of wing dihedral angle on the lateral-directional stability of the model with the vertical tail on are presented for $\tau = 0^\circ$ and $\tau = 13^\circ$, respectively, in figures 7(a) and 7(b). With $\tau = 0^\circ$ the model was directionally unstable except for $\Gamma = 110^\circ$ at $\alpha < 14^\circ$; whereas with $\tau = 13^\circ$ the model was directionally stable for the intermediate wing dihedral angles ($\Gamma = 30^\circ$, 60°, and 90°). All combinations of dihedral and toe-in angles investigated resulted in positive effective dihedral over the test angle-of-attack range. The smaller dihedral angles provided greater effective dihedral which also increased with increasing angle of attack. Comparison of figures 7(a) and 7(b) indicates that the positive toe-in angle enhanced the stability characteristics for all dihedral angles except $\Gamma = 110^\circ$.

SUMMARY OF RESULTS

Hypersonic wind-tunnel tests have been conducted to determine the static longitudinal and lateral-directional aerodynamic characteristics of a spacecraft concept with a variable-dihedral delta wing over the angle-of-attack range from -5° to about 38°. Wing dihedral angles of 0°, 30°, 60°, 90°, and 110° at 0° and 13° of wing toe-in were investigated. The results of this investigation are summarized as follows:

1. The model was longitudinally stable about the selected center-of-gravity position of 0.70 body length over the angle-of-attack range only for wing dihedral angles of 0° and 30° at both toe-in angles.

2. Untrimmed maximum lift-drag ratios of about 2 and 1.9 were obtained for the wings with 0° dihedral at 0° and 13° toe-in, respectively.

3. With 0° of wing toe-in, the model was directionally unstable for all dihedral angles except $\Gamma = 110^{\circ}$ at angles of attack below 14°.

4. With 13° of wing toe-in, the model was directionally stable for the intermediate dihedral angles of 30°, 60°, and 90°.

5. All combinations of wing dihedral and toe-in angles investigated resulted in positive effective dihedral over the test angle-of-attack range.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., August 24, 1971.

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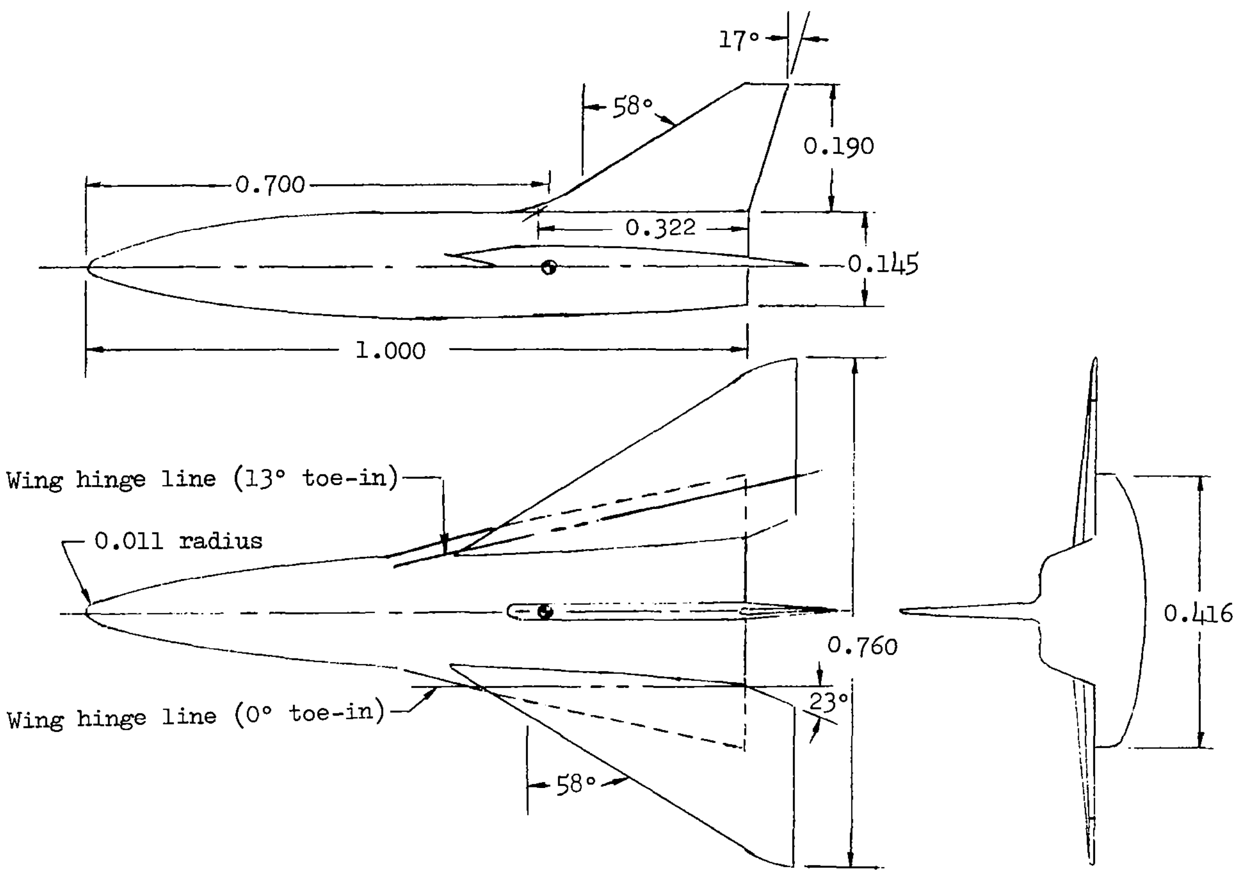
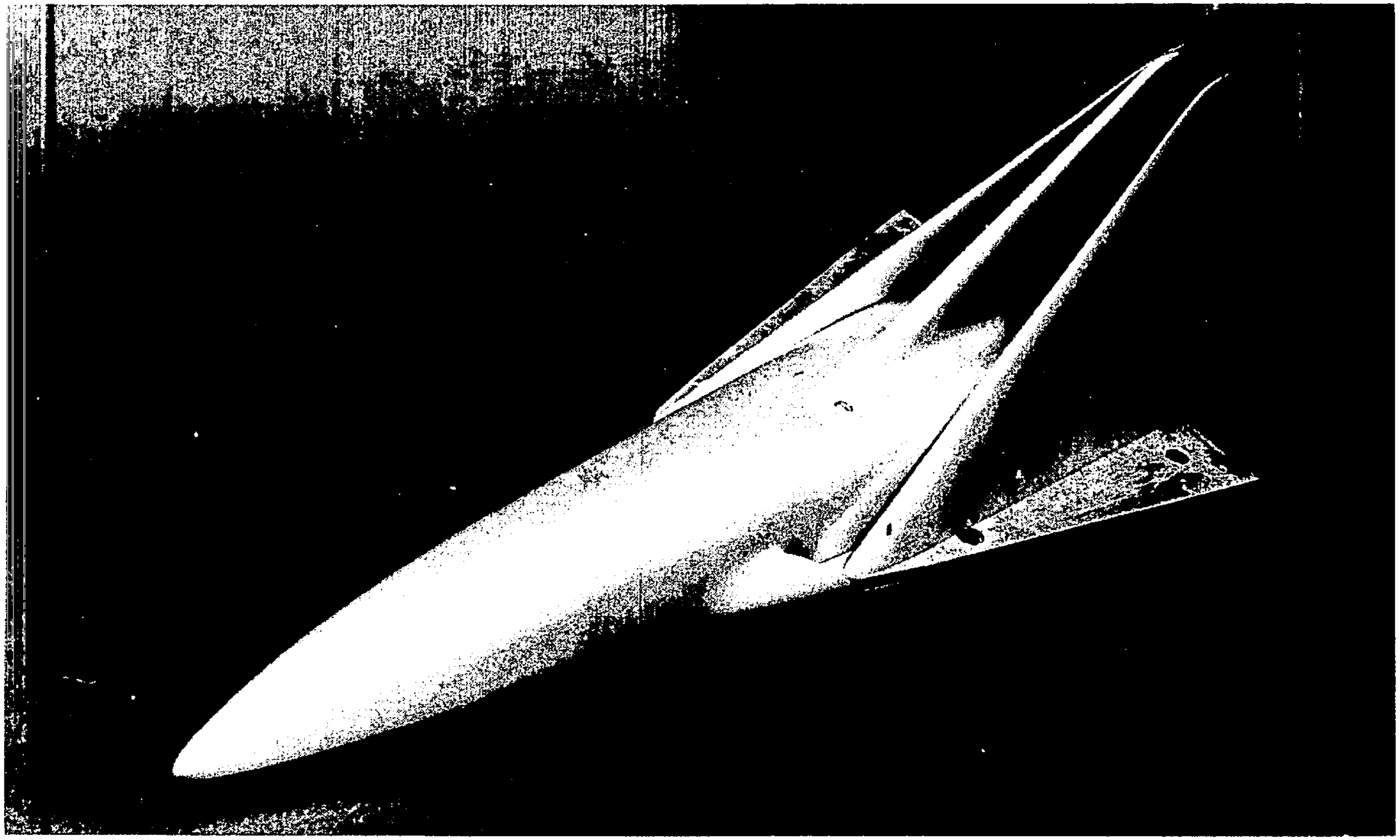


Figure 1.- Sketch of model used in investigation. All dimensions are normalized with respect to body length, l = 20.35 cm.



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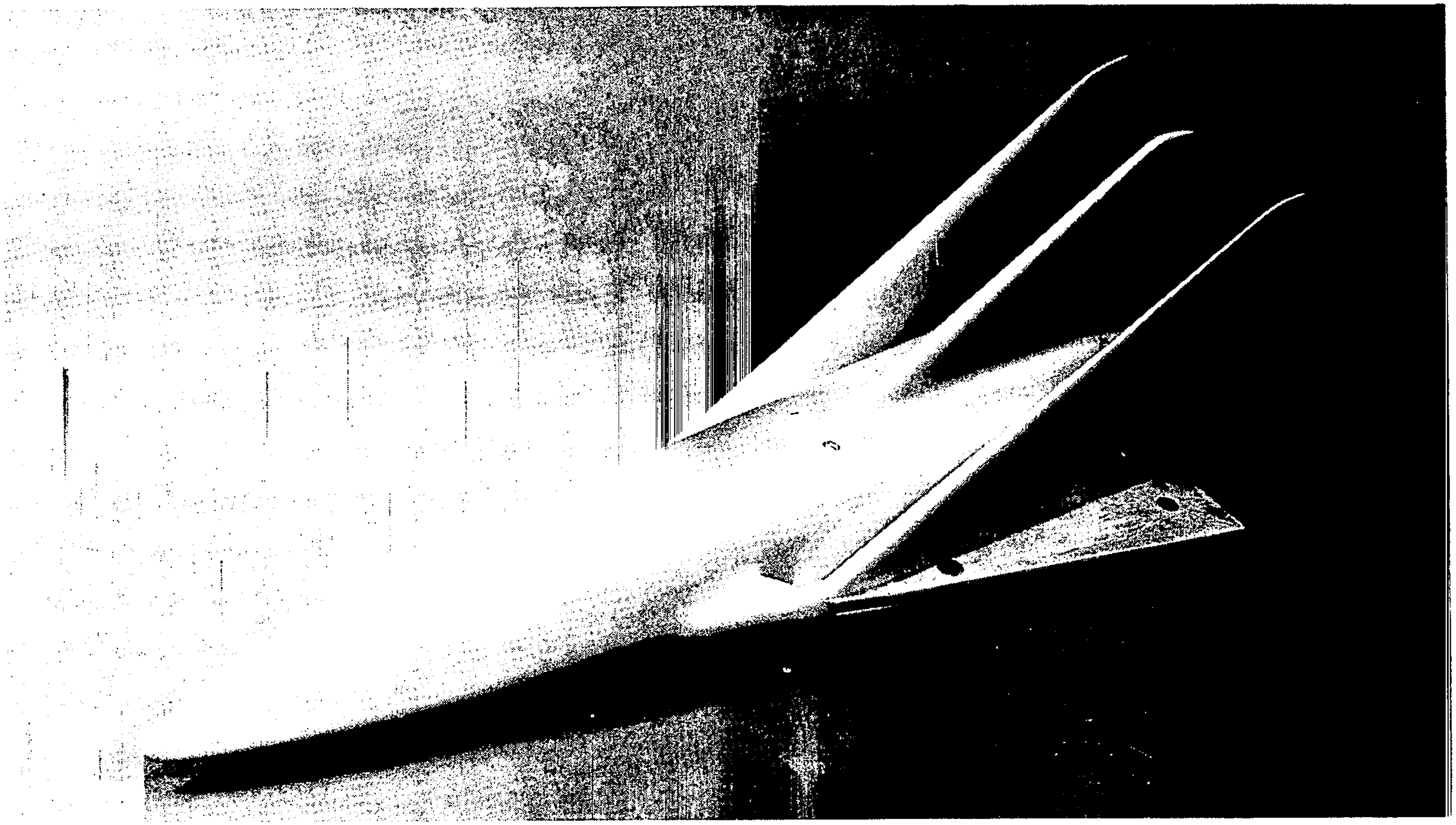
(a) $\Gamma = 110^{\circ}$.

Figure 2.- Photographs of model.



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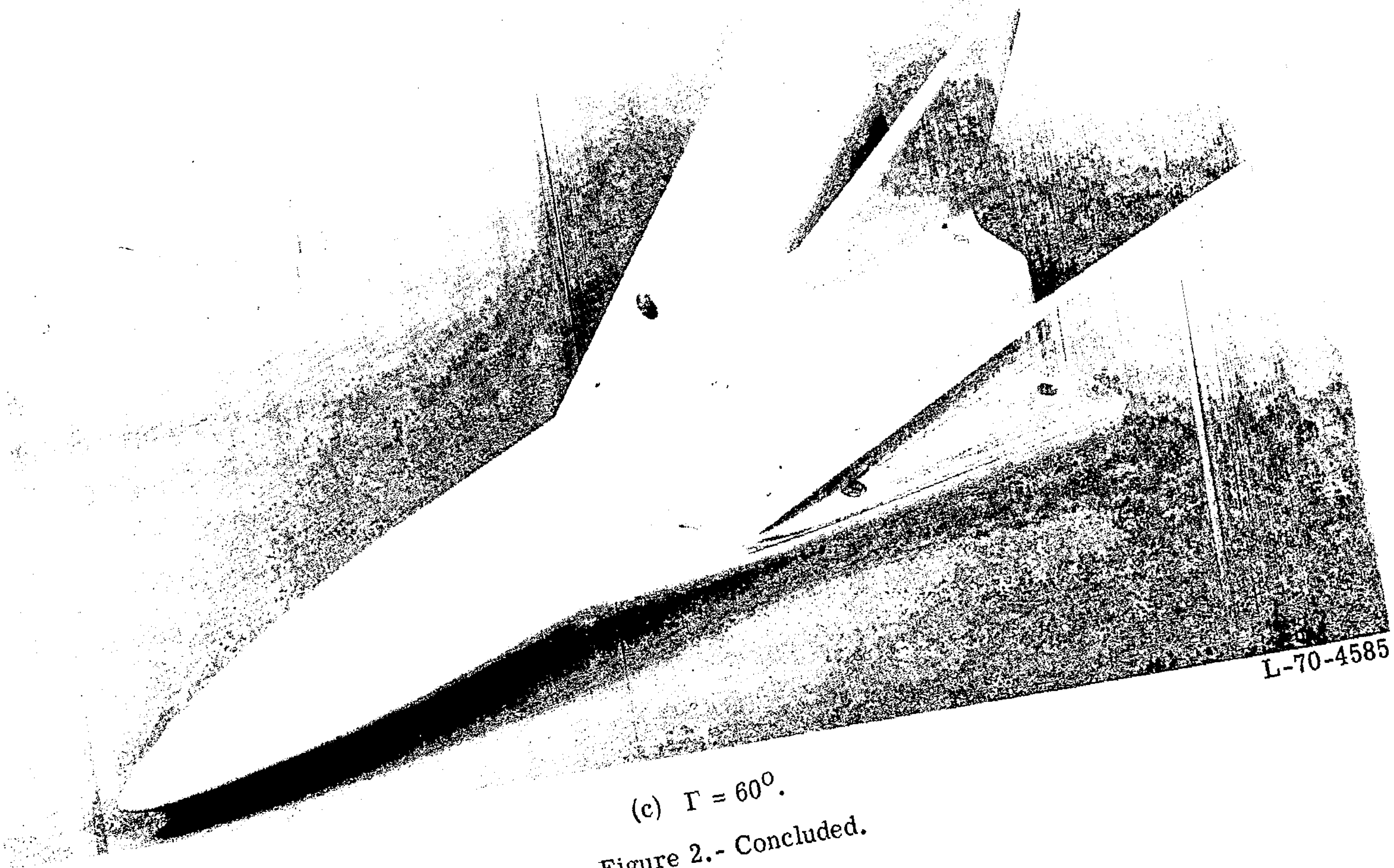
(b) $\Gamma = 90^{\circ}$.

Figure 2.- Continued.



(c) $\Gamma = 60^{\circ}$.

Figure 2.- Concluded.

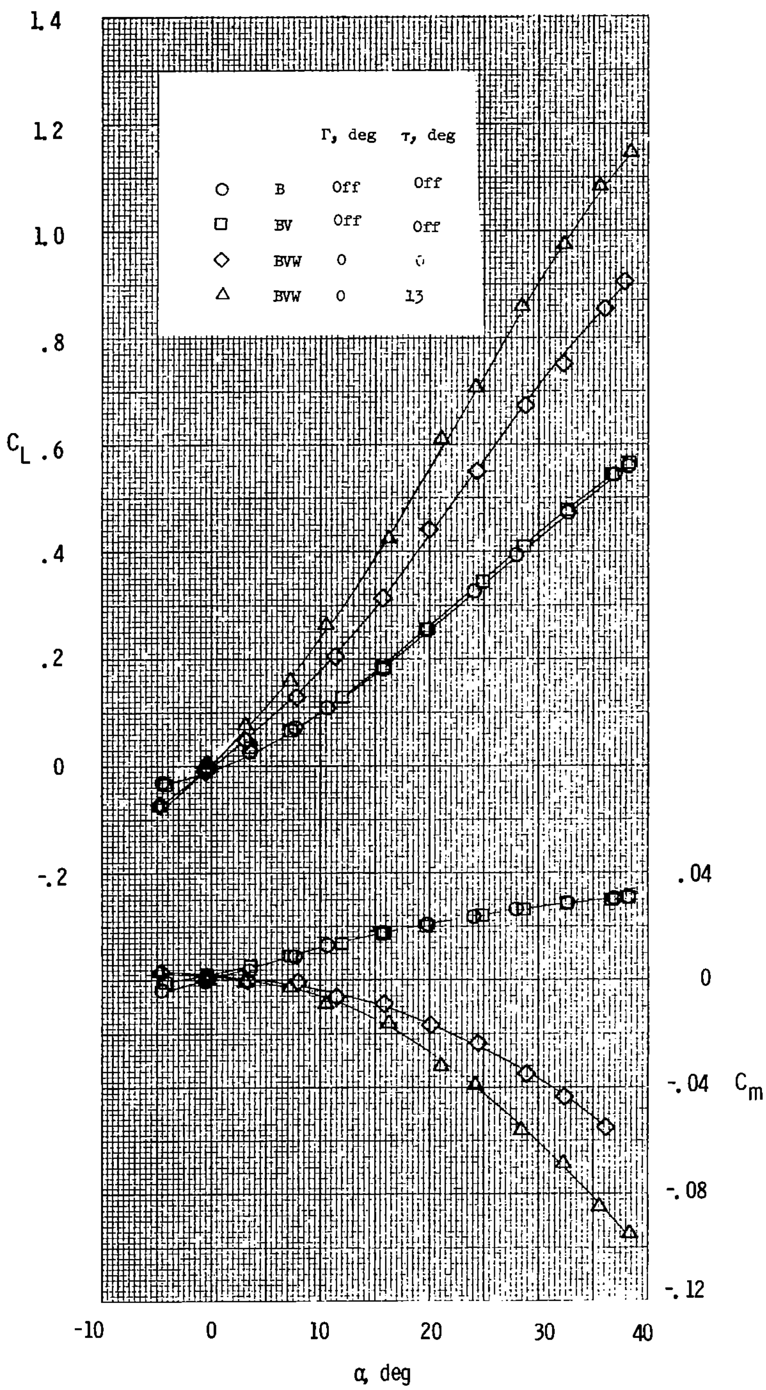


Figure 3.- Effect of component buildup on the longitudinal aerodynamic characteristics.

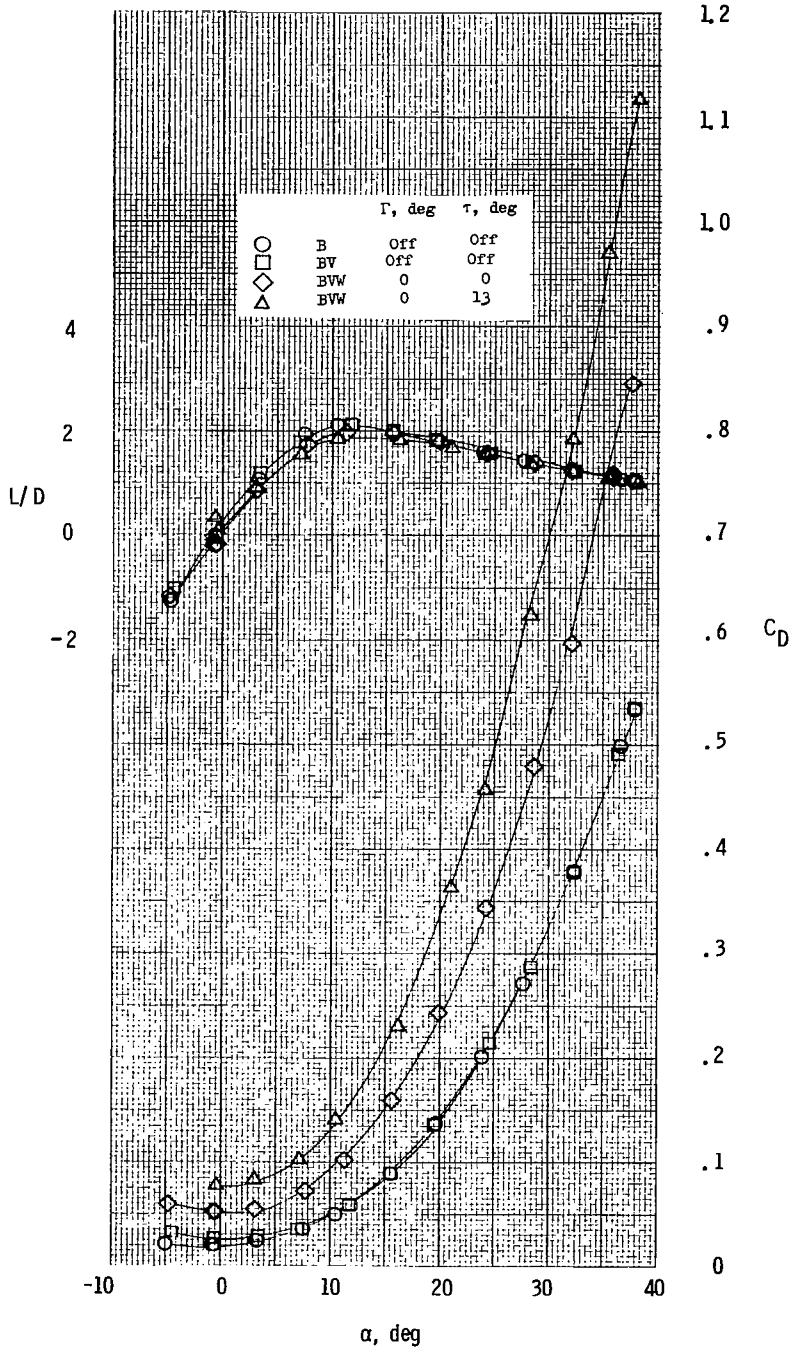


Figure 3.- Concluded.

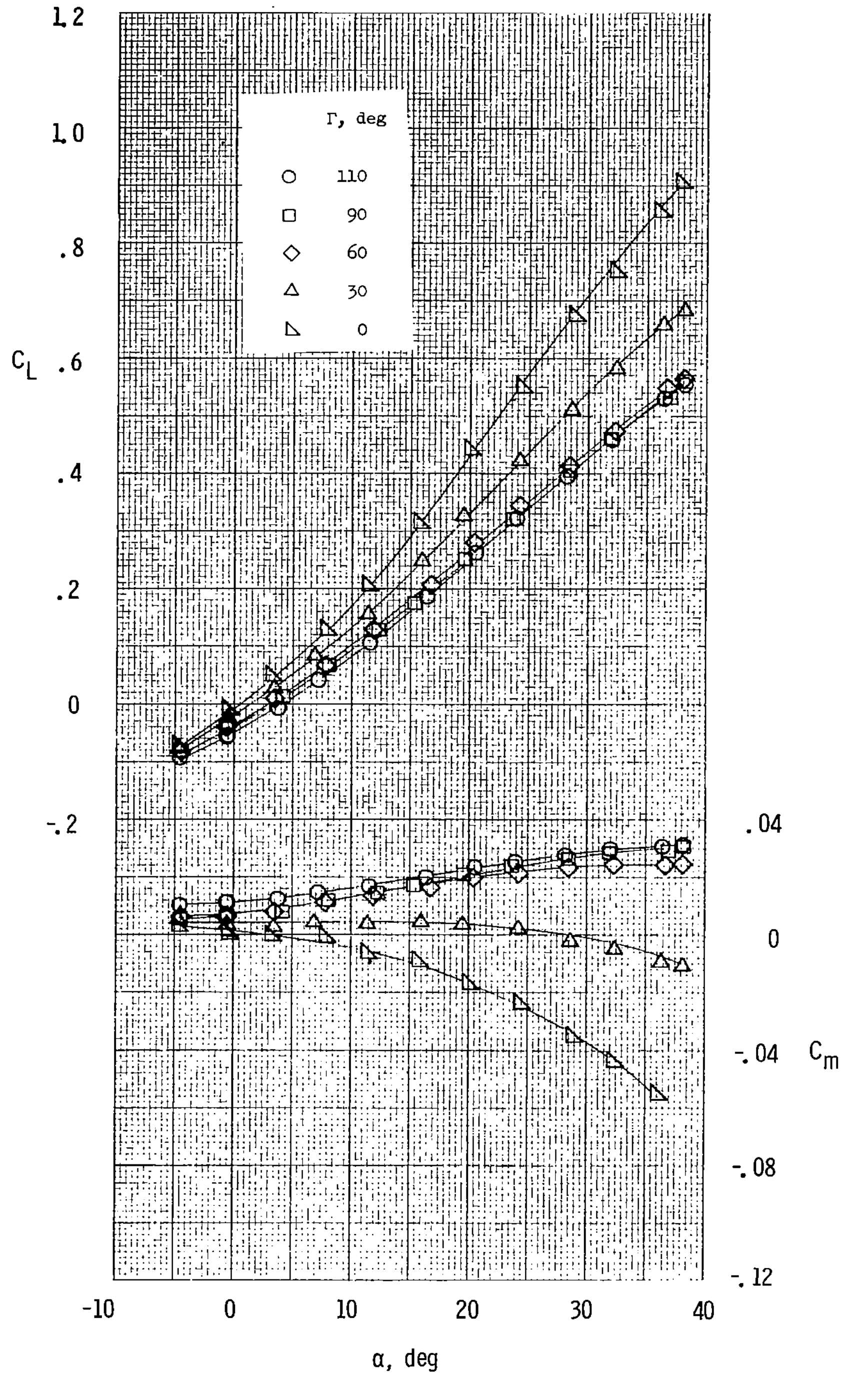


Figure 4.- Effect of wing dihedral angle on the longitudinal aerodynamic characteristics. $\tau = 0^{\circ}$.

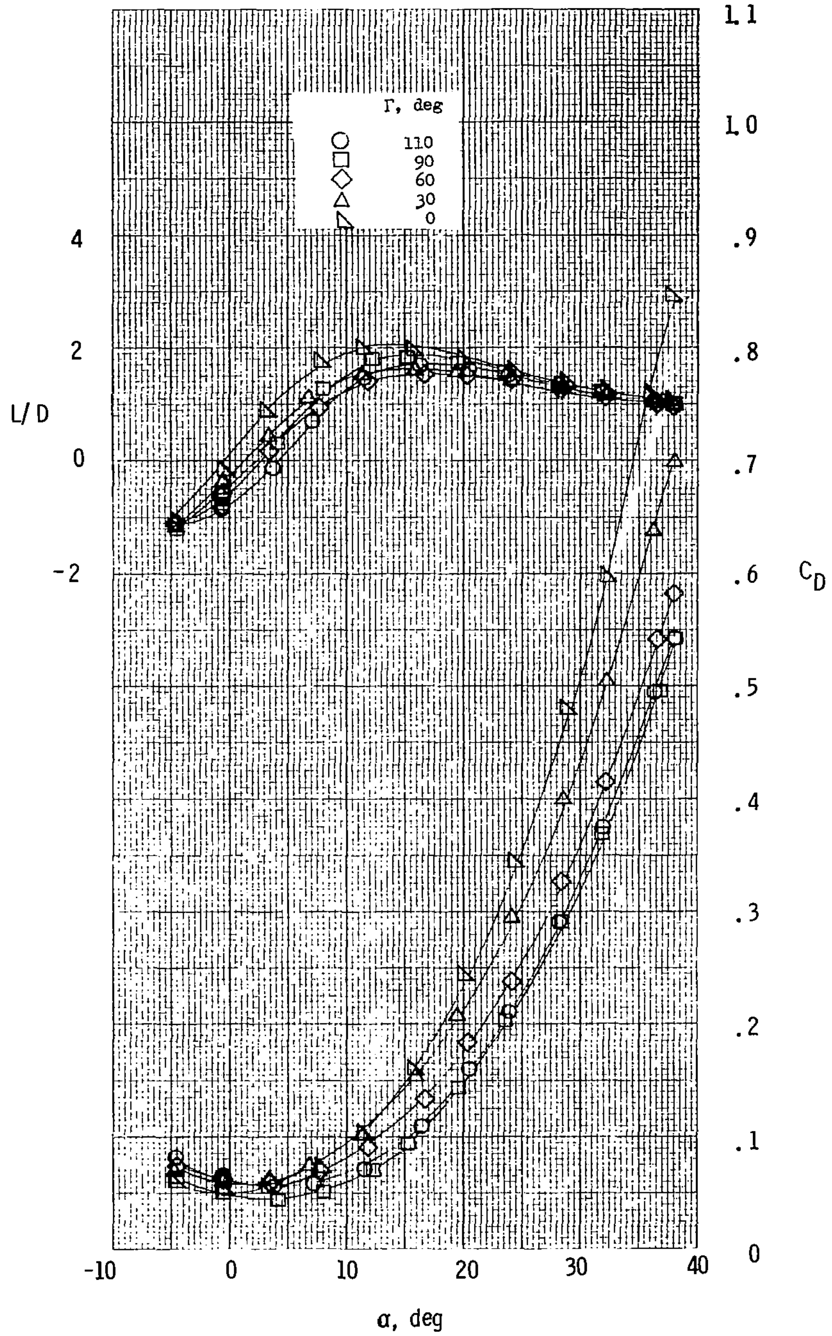


Figure 4.- Concluded.

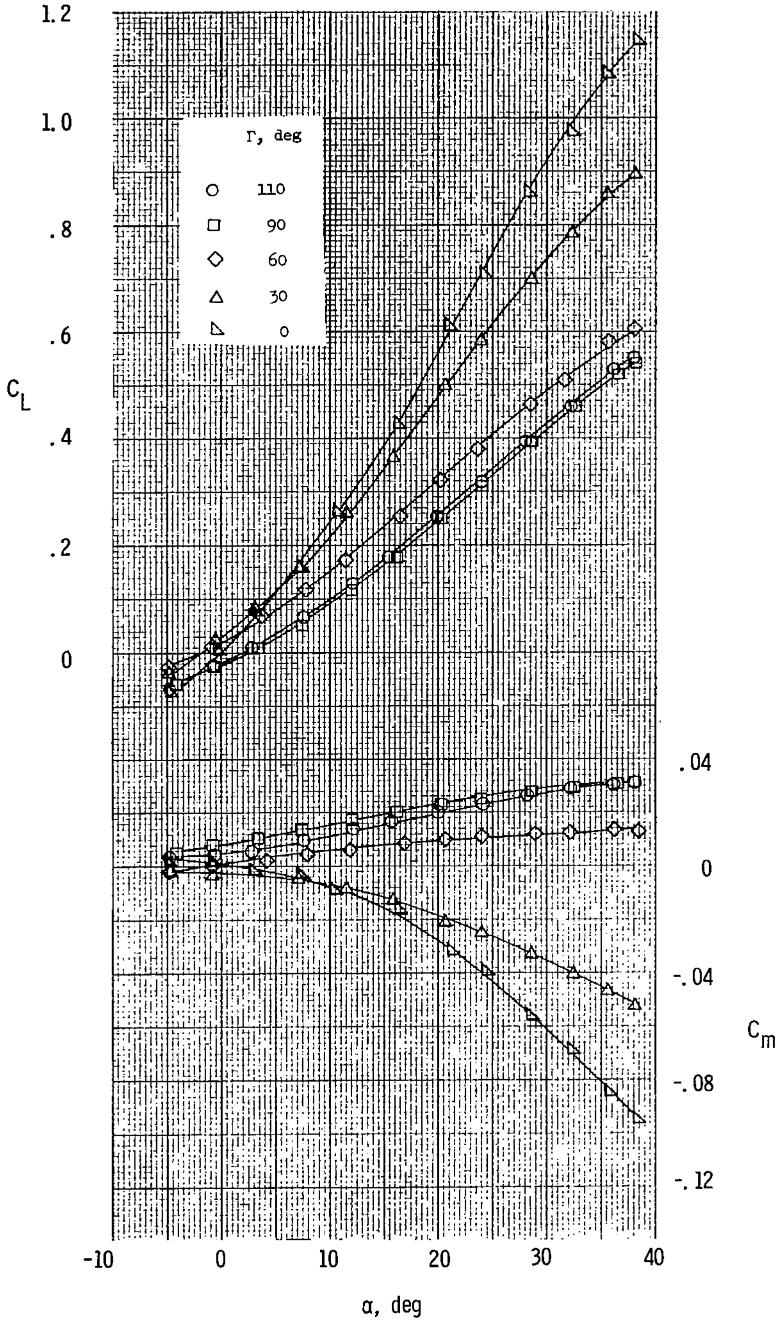


Figure 5.- Effect of wing dihedral angle on the longitudinal aerodynamic characteristics. $\tau = 13^{\circ}$.

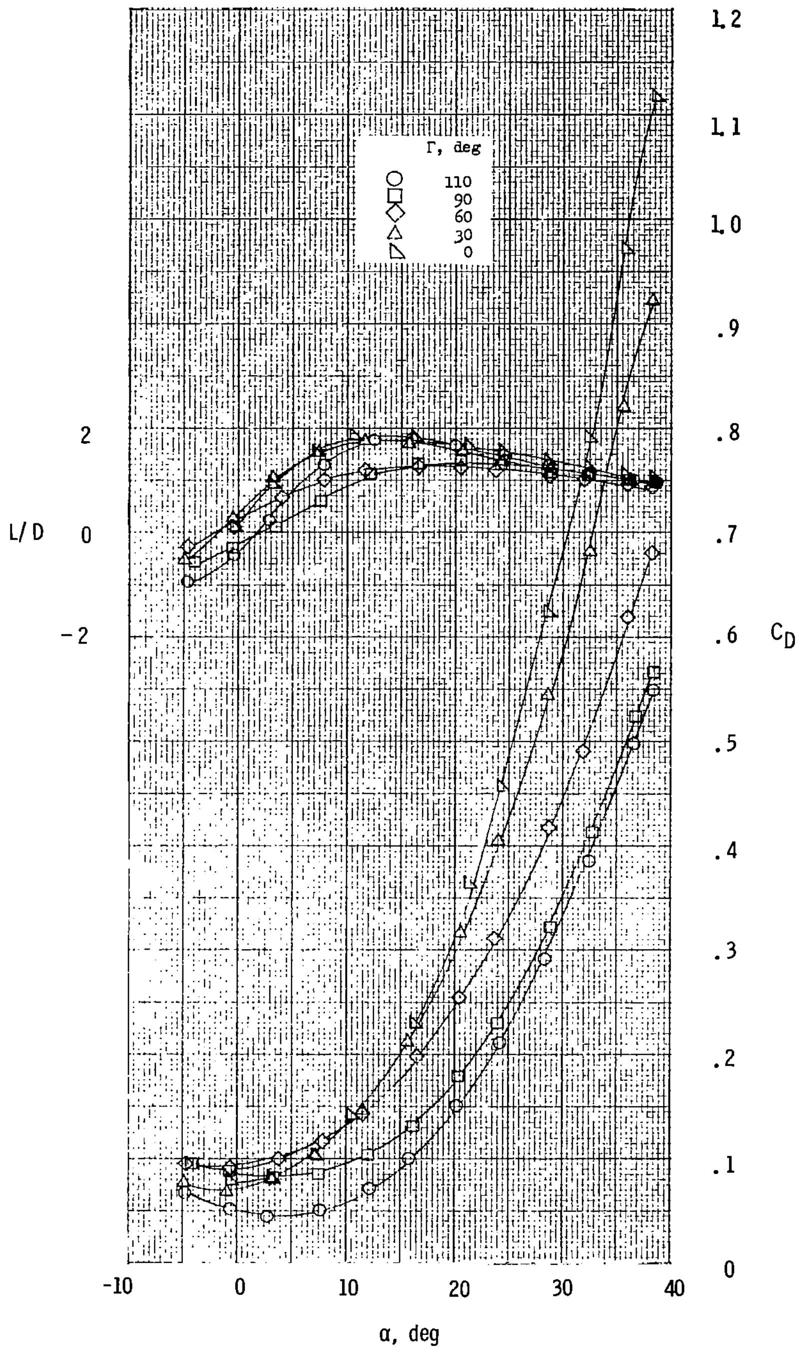


Figure 5.- Concluded.

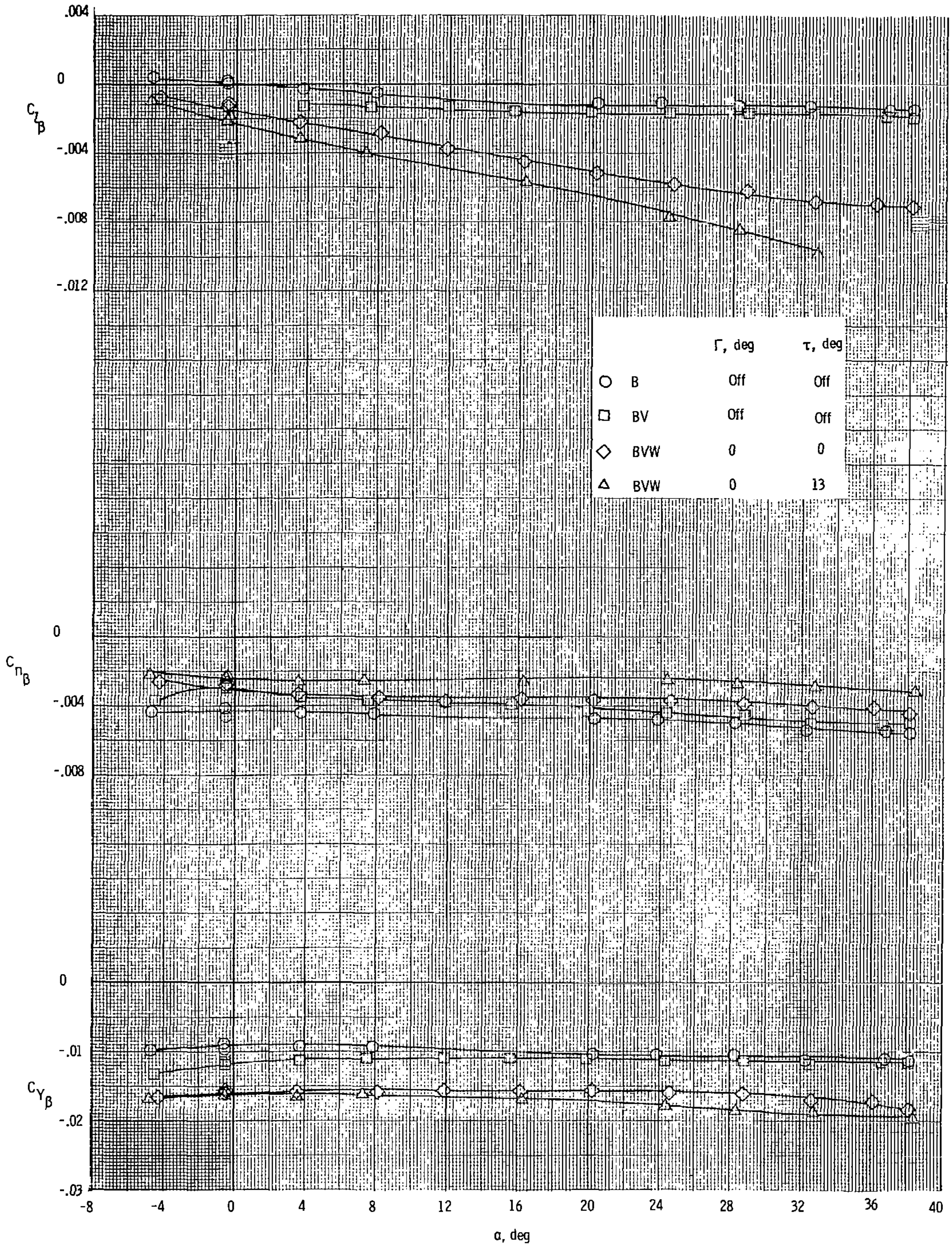
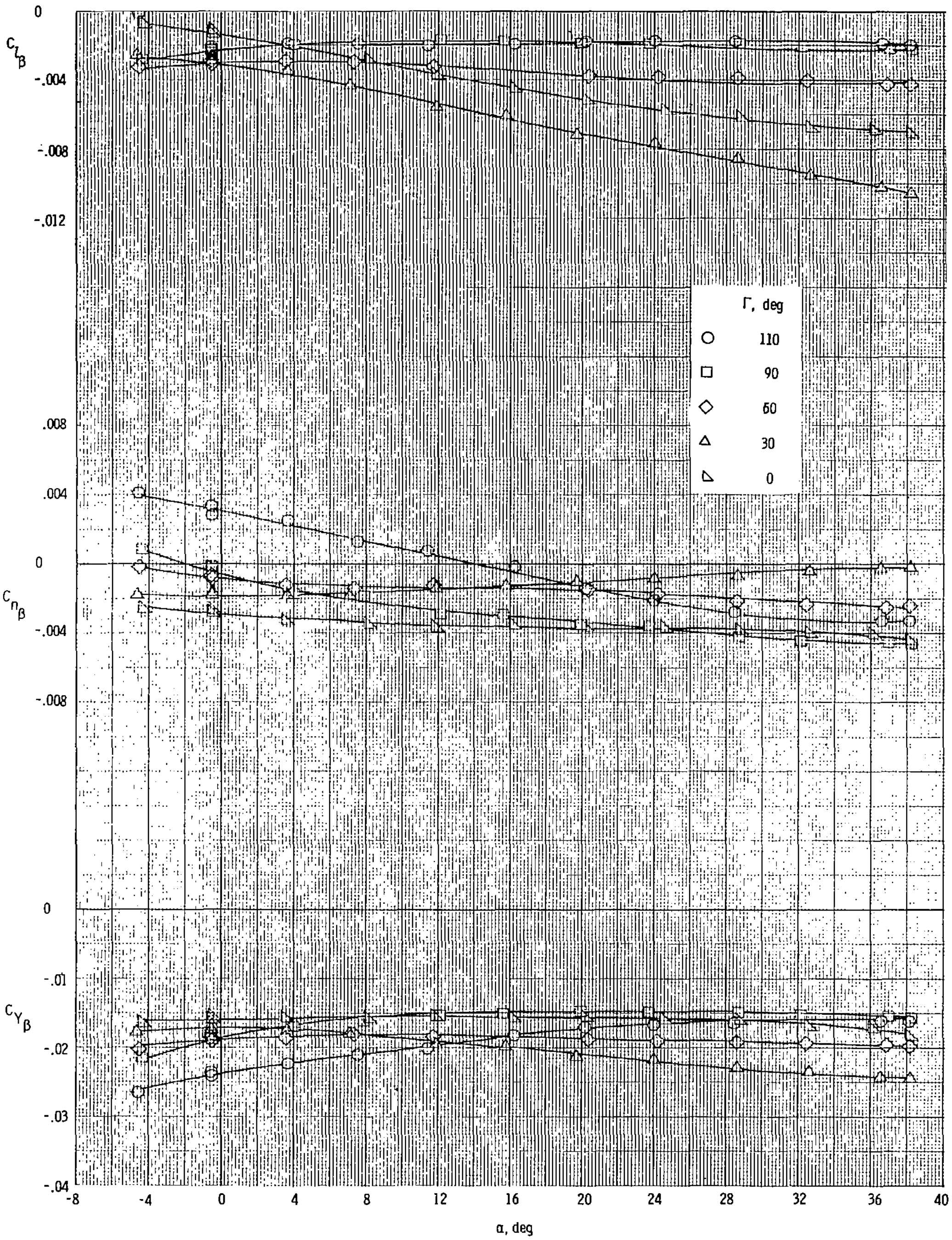
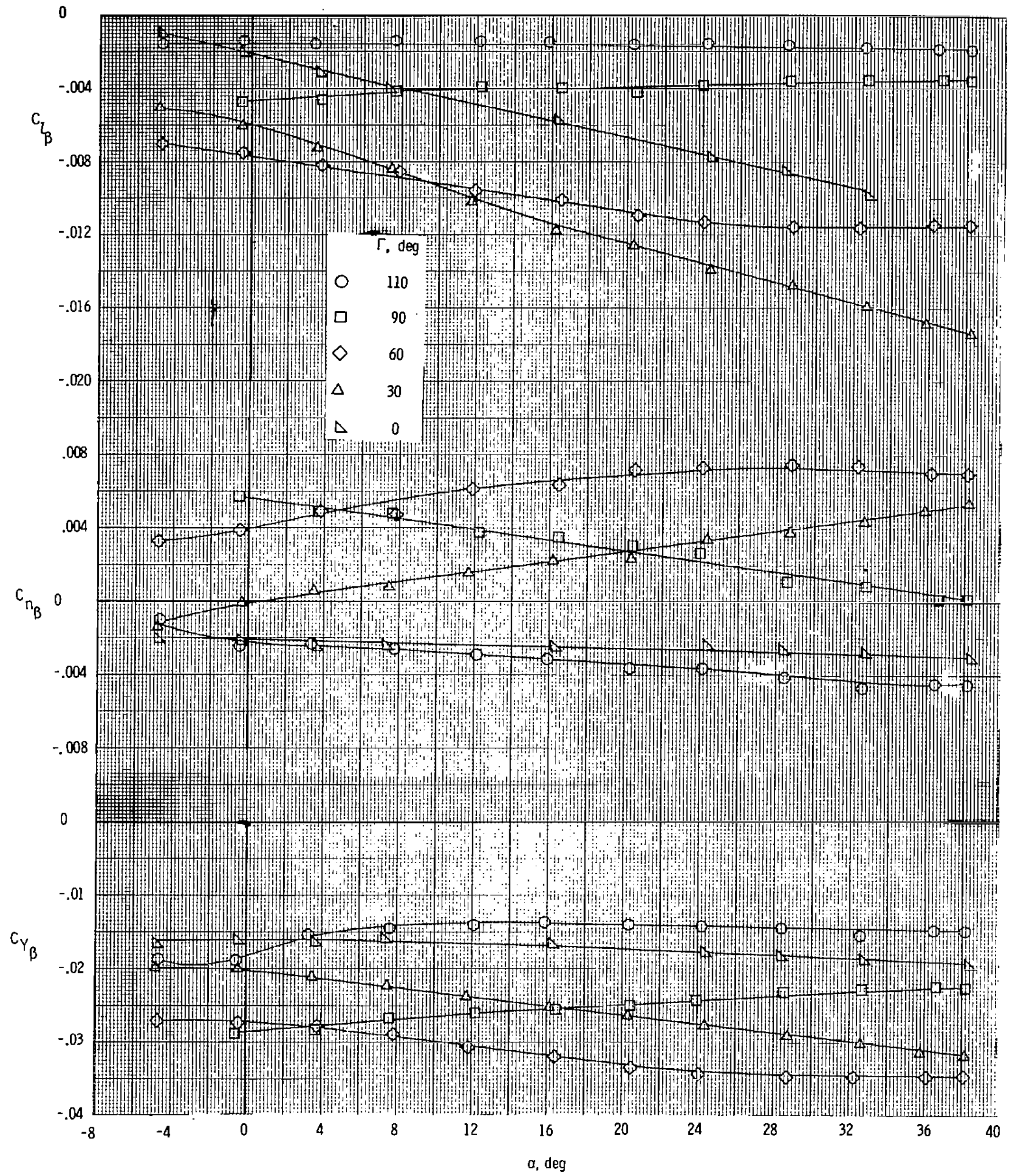


Figure 6.- Effect of component buildup on the lateral-directional stability characteristics.



(a) $\tau = 0^{\circ}$.

Figure 7.- Effect of wing dihedral and wing toe-in angle on the lateral-directional stability characteristics.



(b) $\tau = 13^{\text{o}}$.

Figure 7.- Concluded.

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